Boundary Layer Coherent Structures (MBL ARI)

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Long Term Goals

It is well known that a substantial portion of the air/sea fluxes of heat, moisture, and momentum is accomplished via intermittent processes (Khalsa and Greenhut 1985), processes that are poorly understood at the present time. Recently, Mahrt (1989) and Sikora and Young (1993) have demonstrated that coherent structures in the marine boundary layer (MBL) are responsible for this flux intermittency. These coherent structure types include such secondary circulations as two-dimensional rolls (cloud streets), three-dimensional convective cells (thermals), and shear-driven eddies (billows) (Brown 1980). These features occur in different atmospheric boundary layer thermal stratification and shear regimes; some are forced primarily by thermodynamic, and others by dynamic, mechanisms.

Our ultimate goal is to determine the mechanisms underlying the intermittency in air/sea fluxes produced by these coherent structure types. As summarized below, we are using a variety of complementary statistical/mathematical approaches to objectively identify the spatial and temporal characteristics of these structures. Our primary data sources include both the high resolution output produced by the Penn State version of Moeng's Large-Eddy Simulation (LES) code (e.g. Schumann and Moeng 1991) and observations from the MBL ARI experiments performed in 1995 off the California coast.

Objectives

Our immediate scientific objective is to complete analysis of the 1995 MBL ARI field program datasets using our own specialized implementations of these statistical/mathematical approaches (Rinker 1995; Rinker *et al.* 1995; Rinker and Young 1996; Winstead *et al.* 1995; Rohrbach 1996; Suciu 1996; Rogers 1997; Rogers *et al.* 1997; Shirer *et al.* 1997). To identify the spatial and temporal behavior of the coherent structures, we use obliquely rotated principal component analysis (PCA). To capture the contribution of each coherent structure type to intermittency, we have chosen the capacity dimension (Takens 1981; Henderson and Wells 1988) and the multiscale line-length algorithm of Higuchi (1988).

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Approach

PCA has been shown to be capable of distinguishing and quantitatively describing multivariate structures within the atmosphere (e.g., Richman 1986; Preisendorfer 1988; Alexander *et al.* 1993). Using both standard and newly developed PCA algorithms, we have studied several LES datasets to see which principal components (PCs), or coherent structure types, are largely independent of the large-scale forcing and which vary sensitively with it (Rinker 1995; Rinker *et al.* 1995; Rinker and Young 1995; Winstead 1995; Winstead *et al.* 1995; Rohrbach, 1996; Suciu 1996). These results have identified, for each forcing regime, the primary physical processes and coherent structure types associated with air-sea flux intermittency. Significantly, our applications of the PCA algorithms to idealized data tests have demonstrated that the method is able to distinguish multiple coherent structure types under several realistic conditions. These tests provide proof that PCA can yield valid results without having an *a priori* conceptual model, as required of previous (conditional sampling) methods.

To identify the individual coherent structure types, we use both the spectral coherence of pairs of temporal PC score series as well as their chaotic behavior. Nonperiodic, temporal variation is chaotic if the details of a particular time series can not be simulated beyond a few cycles with virtually identical initial conditions, a situation typical of most atmospheric flows. Our hypothesis is that each coherent structure type has its own identifiable chaotic behavior as revealed by how the fractal dimension estimates vary as a function of scale. We have tested this hypothesis using both the capacity dimension (Suciu 1996; Rogers 1997; Rogers *et al.* 1997) and the Higuchi (1988) multiscale algorithm (Winstead 1995; Winstead *et al.* 1995). Our datasets were obtained from fixed columns in an LES domain (Winstead 1995; Winstead *et al.* 1995; Suciu 1996) and the 1995 MBL ARI observations (Rogers 1997; Rogers *et al.* 1997).

Work Completed

During the last year we acquired the 1995 RP FLIP MBL ARI dataset and calibration codes from Dr. Jim Edson of WHOI and Dr. Carl Friehe of UC-Irvine. Graduate students Aric Rogers and Jeremy Rishel completed calibration of these data. Aric Rogers finished his MS thesis (Rogers 1997) describing a case study of the convective atmospheric surface layer using these data and the coherent structures identification algorithm described above. He presented these results (Rogers *et al.* 1997) at the American Meteorological Society's 12th Symposium on Boundary Layers and Turbulence held in Vancouver, British Columbia, July 28-August 1, 1997. Also during this past year, the paper by Shirer *et al.* (1997) detailing their improved algorithm for estimating the correlation dimension of atmospheric time series was published.

Results

Graduate student Laura Suciu (1996) extended the capacity dimension algorithm of Henderson and Wells (1988) in a way similar to that done for the correlation dimension by Shirer *et al.* (1997). This algorithm plays a fundamental role in the coherent structures identification algorithm developed and successfully tested on the 1995 MBL ARI dataset by graduate student Aric Rogers. This algorithm begins by applying PCA to the set of 54 variables observed on RP

FLIP; the variance in the data was well captured by 20 of the 54 PCs. These PCs depict the linked vertical structure and temporal behavior of the atmospheric variables through their factor profiles and score series, respectively. These 20 PCs may be separated into groups representing different coherent structure types by first determining the spectral coherence of pairs of score series and then comparing the capacity dimension curves of individual score series. For example, the right plot in Fig. 1 shows the capacity dimension curves for all 20 score series derived from a 6600-second set of observations obtained in the convective boundary layer on May 4, 1995. The considerable scatter among these curves indicates that more than one coherent structure type coexisted in the MBL on that day. Those dimension curves that group well, such as the six shown in the left plot of Fig. 1, represent one of these structures. As shown by Rogers (1997) and Rogers *et al.* (1997), reconstruction of the observations using these six PCs provides a representation of the wind direction and thermal characteristics of microfronts on the upwind edge of surface layer plumes (e.g., Kaimal and Businger 1970) whose wind speed variance is captured by another set of four PCs (not shown). A third group, also not shown, represents small-scale wind/wave interaction.

Impact/Applications

The observational and modeling studies currently being completed will lead to improved understanding of the flux intermittency commonly observed in the MBL. This will help advance our overall understanding of processes that affect the state of the sea surface.

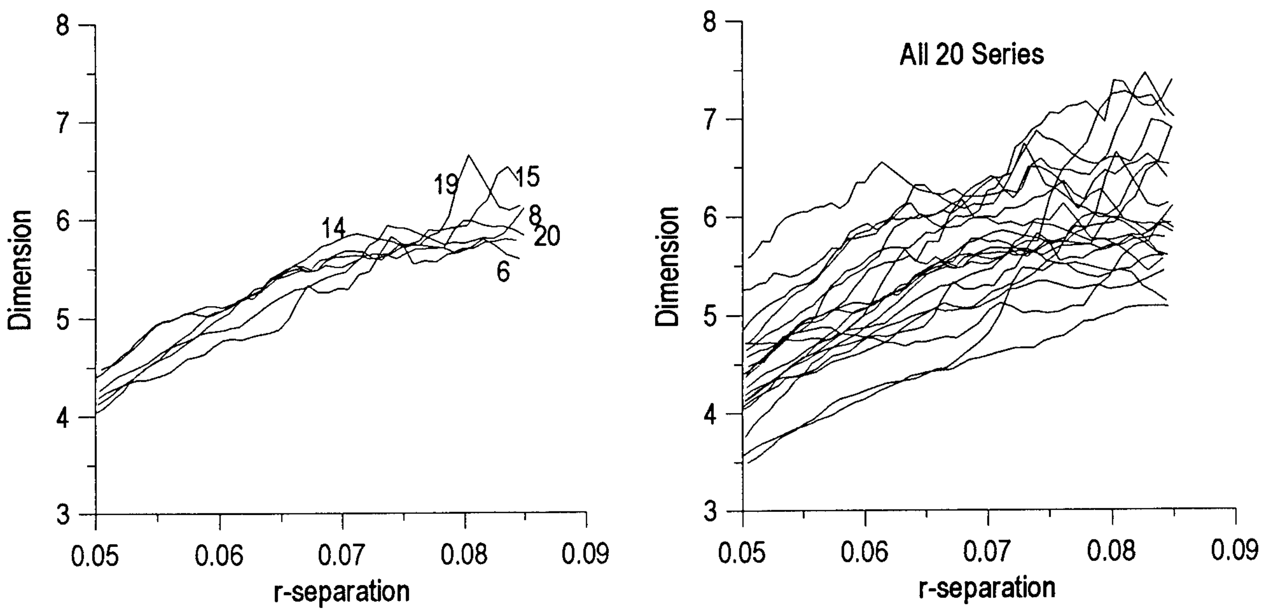

Figure 1. Capacity dimension estimates for all 20 principal component score time series (right graph) and for the six that group together (left graph) that were obtained from a 6600-second time series of 54 variables observed on May 4, 1995 during the MBL ARI deployment of RP FLIP (from Rogers 1997). The six that group together represent the wind direction and thermal characteristics of microfronts on the upwind edge of convective surface-layer plumes (e.g., Kaimal and Businger 1970).

Transitions

Improved understanding of air/sea flux intermittency will lead to improved means for interpreting sea surface roughness patterns on SAR imagery. This improvement will become possible as we obtain an increased understanding, via this ARI project, of the vertical momentum transports by the various coherent structure types. Collaborative work with Don Thompson and Robert Beal of JHUAPL funded by ONR is taking advantage of this approach to derive from SAR imagery quantitative estimates of boundary layer depth, surface wind speed and direction, and air-sea fluxes.

Related Projects

Drs. Jim Edson and Carl Friehe have suggested that another deployment of RP FLIP is necessary to sample the near-surface regions of the atmospheric and oceanic boundary layers much better than was possible during the MBL ARI. The goals of such an experiment would be to understand the processes in the wavy boundary layer much better through the study of the interactions among ocean waves, surface layer oceanic and atmospheric eddies, and mixed-layer atmospheric eddies. Our objective algorithm will provide one means for identifying the coherent structure types in the wavy boundary layer and for quantifying their flux intermittency.

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<presentations> Shirer, H.N., L. Suciu, R. Wells, N.S. Winstead, and A. Rogers. Identifying and classifying MABL coherent structures based on their chaotic behavior. MBL ARI Workshop, La Jolla, CA, October 28-30, 1996.

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TOGA Surface Processes Group (1991-present)
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Mountain Meteorology Committee (1992-1995)
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Awarded sabbatical leave for '94-'95 academic year; majority of time to be spent at Risø National Laboratory, Roskilde, Denmark, in part to collaborate on MBL ARI-funded RASEX field project

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